Optimization of antiproton injection to the Recycler

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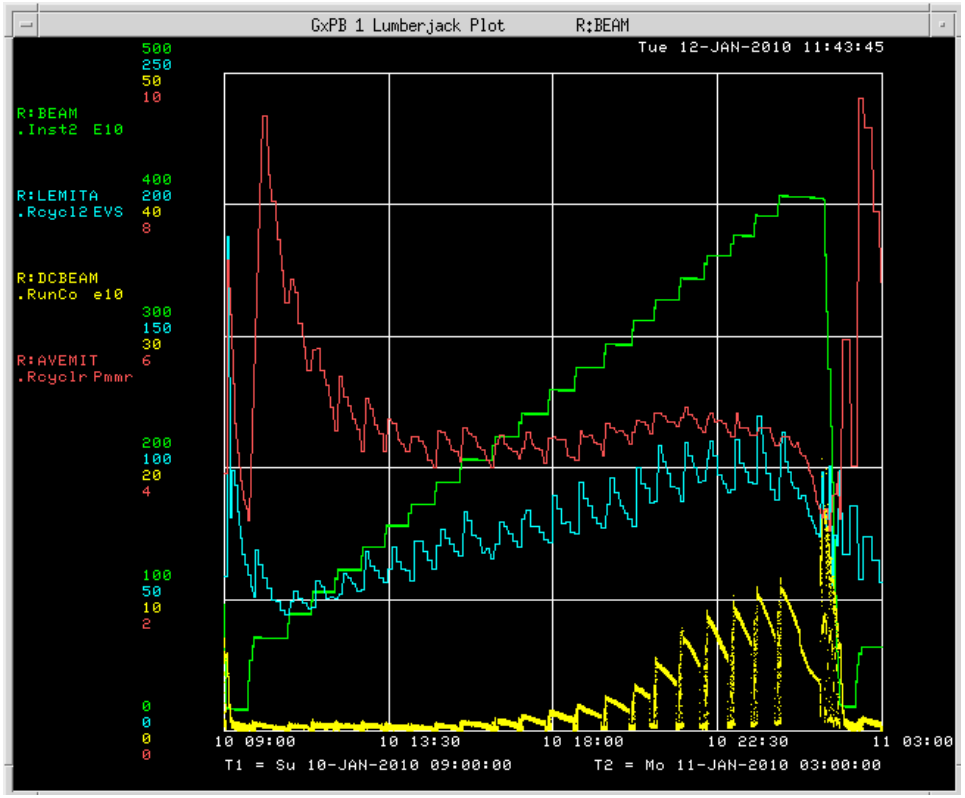
Introduction

- Recycler mission: accumulate and cool antiprotons, coming from the Accumulator, for the Tevatron shots
  - ➢ Accumulation ("stashing")
    - Transfers of ~17E10 every ~40 min
    - Shots to TeV with ~400E10
      - Maximum 527E10- no problems
    - Maximum number of antiprotons is determined by Tevatron capabilities and by optimization of the complex's operation
  - ➢ Cooling
    - Antiproton brightness increases in the Recycler by a factor of 60

$$\text{Brightness} = \frac{(\text{Number of antiprotons})}{(\text{Longitudinal Emitance}) \cdot (\text{Horizontal Emittance}) \cdot (\text{Vertical Emitance})}$$

    - Maximum brightness is determined by instabilities in the Recycler
- Still, we are improving the strength of electron cooling and the Recycler procedures
  - ➢ The goal is to minimize antiproton losses in the Recycler
  - ➢ The recent addition is a **modification of the injection procedure**

Recycler stashing cycle



RR stashing cycle.

January 10-11, 2010.

Green – number of pbars, 100E10/box

Blue – longitudinal emittance, 50eVs/box

Yellow – DC beam, 10E10/box

Red – average transverse emittance (n 95%), 2 π mm·mrad/box

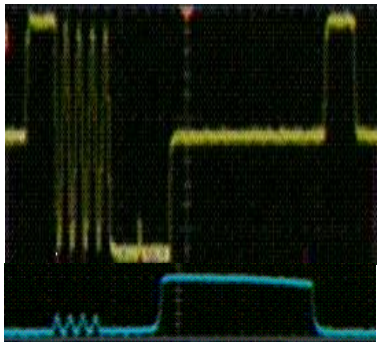
- Different behavior of transverse and longitudinal emittances through the stashing cycle

- For larger number of pbars, an increase of
  - the transverse emittance is less
  - the longitudinal emittance is more
  - the amount of DC beam is more

"DC beam" = particles not captured into RF bucket

- The stash may be perturbed too much during injections

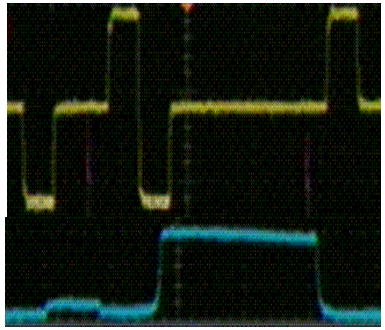
Recycler injection before modification



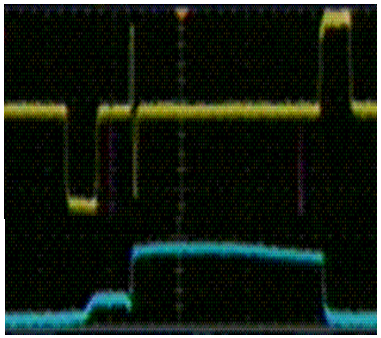
Four antiproton bunches are injected into matching 2.5 MHz buckets

- Longitudinal injection
  - The main beam is kept between two rectangular RF barriers at 5.8 μs
  - Antiprotons arriving from Accumulator are injected into a free part of the same orbit
  - After merging, the final bunch has an increased longitudinal emittance
  - Typical efficiency of the transfer is ~ 95% (from Acc. to RR)

2.5 MHz structure is adiabatically removed; the injected beam is in a rectangular bucket

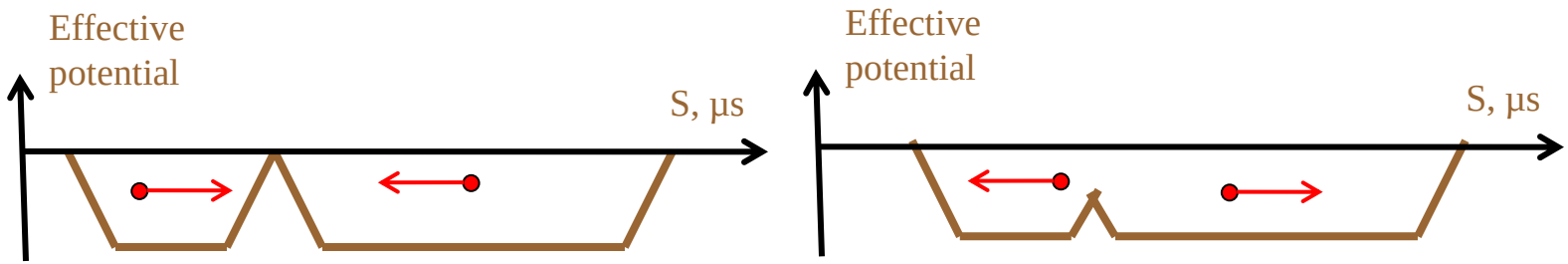


Oscillograms of RF voltage and beam profile during injection. The horizontal span is one revolution period, 11μs.



The injected beam is merged with the main bunch. Before merging , it is compressed from 84 to 50 bckts (C. Bhat)

Direction of optimization

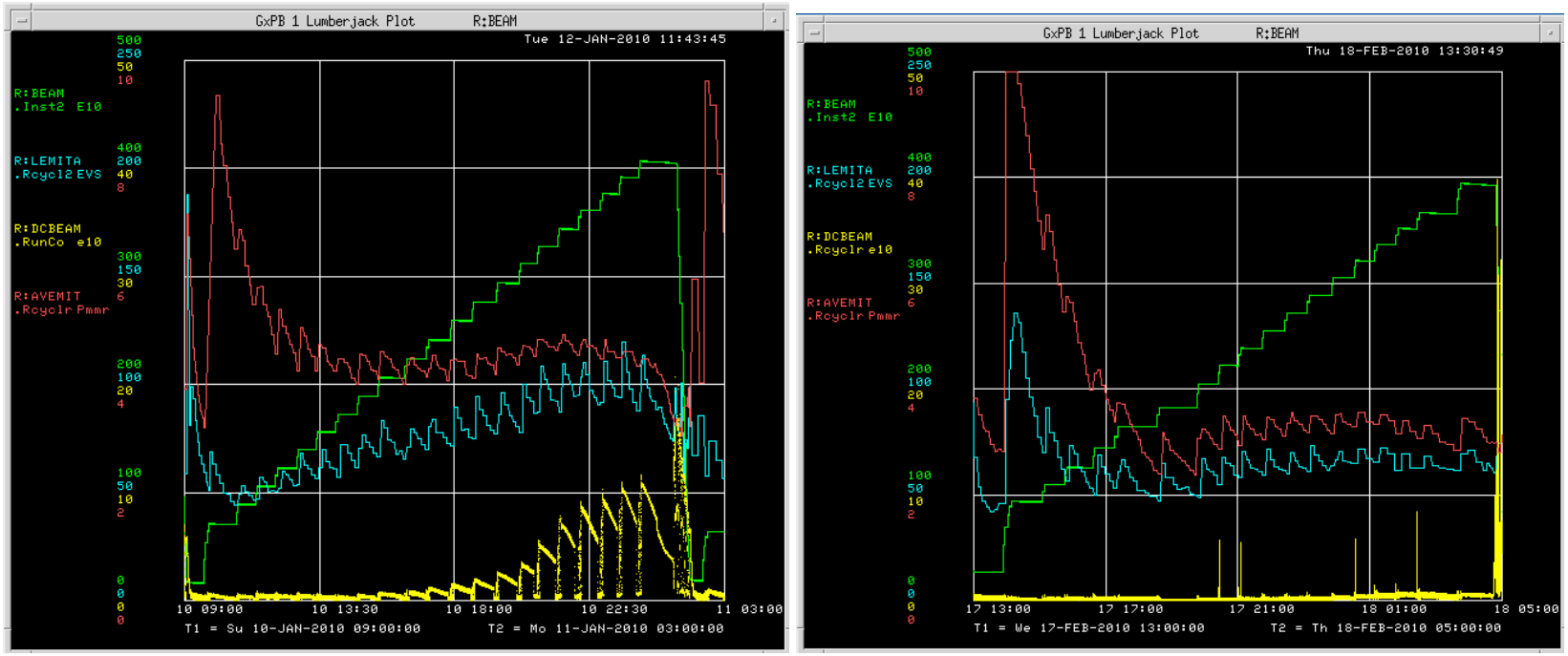


- When the barrier between the stash and the injected portion collapses, action of all particles increases approximately as the ratio of final and initial length of synchrotron trajectory.
  - If longitudinal phase densities and momentum spreads are the same in two portions, the final rms emittance is a sum of their emittances

$$\varepsilon_1 = \varepsilon_0 + \varepsilon_{in}$$

  - At high number of pbars in RR, the phase density of stash is much higher that one of the injected beam. It is better to squeeze the injected beam as much as possible before merging it to the stash.
- It was implemented on 22-Jan-2010 (C. Bhat, C. Gattuso)

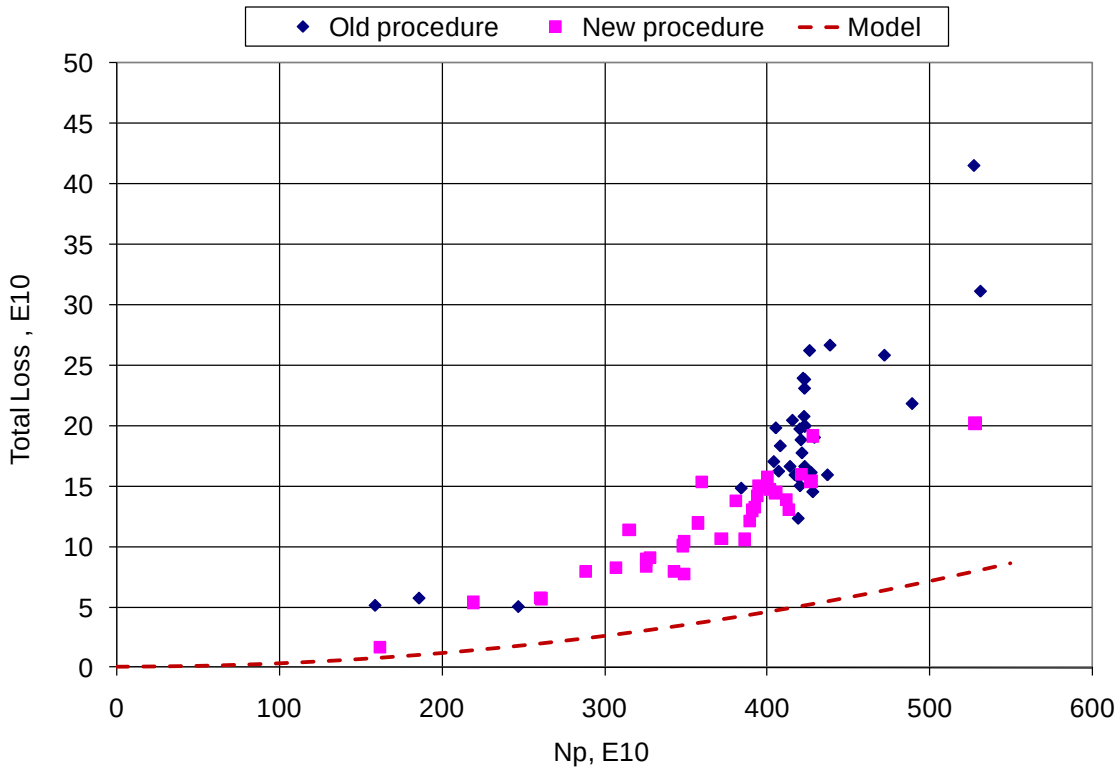
Stashing with modified procedure



RR stashing cycle on January 10-11, 2010 (left) and February 17-18, 2010 (right). Green – number of pbars, 100E10/box; Blue – longitudinal emittance, 50eVs/box; Yellow – DC beam, 10E10/box; Red – average transverse emittance (n 95%), 2 π mm·mrad/box.

- The new procedure looks beneficial
  - the longitudinal emittance is lower
  - amount of DC beam is dramatically lower
    - In addition to this modification, the cooling section's magnetic field was aligned

Beam loss in the Recycler



Total loss per stashing cycle as a function of the maximum number of antiprotons.
Blue – before the modification (23Dec09 – 21Jan10)
Magenta – after (22Jan10-18Feb10)
Dashed line is the model of losses only due to vacuum (800 hrs life time, rate of incoming pbars of 22E10/hr).

- After this modification, the total beam loss per stashing cycle might have decreased by ~1% (of maximum number of antiprotons)
  - Cooling section was aligned around the same time